

Relationship between *Anisakis* infestation and ovarian abnormalities in *Trachurus trachurus* (Carangidae) from the eastern coast of Algeria

by

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Key words

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Abstract. – The objective of the study was to describe the ovarian abnormalities of horse mackerel, *Trachurus trachurus* (Linnaeus, 1758), and to investigate the relationships that may exist between these abnormalities and nematode parasite infestation. 953 specimens of *T. trachurus* were randomly sampled between February 2013 and March 2014. A biometric analysis was conducted for every fish specimen. After dissection, parasites were collected, identified and the infestation rate was calculated. A macroscopic and microscopic study of the gonads was carried out for the infested and non infested fish specimens. The results revealed that only one ovary of the total sample examined had a morphological malformation. However, the microscopic study revealed that almost all the infested females had abnormalities: cyst and atresia increased for 17% and 38% of the examined sub-sample, respectively. The current results showed clearly that ovarian abnormalities were observed in large and old females, which were the most infested.

Résumé. – Relation entre l'infestation par *Anisakis* et les anomalies ovariennes chez le chinchard, *Trachurus trachurus*, des côtes est-algériennes.

L'objectif de l'étude est de décrire les anomalies ovariennes du chinchard, *Trachurus trachurus* (Linnaeus, 1758) et de rechercher la relation pouvant exister entre ces anomalies et l'infestation par les parasites nématodes. Entre février 2013 et mars 2014, nous avons échantillonné 953 spécimens de *T. trachurus* pêchés au niveau de la côte est-algérienne. Une étude biométrique a été réalisée sur chaque spécimen de poisson. Après dissection, la recherche, la récolte et l'identification des parasites ont permis le calcul du taux d'infestation. Une étude macroscopique et microscopique des gonades a été réalisée pour les spécimens infestés et non infestés de ce poisson. Nos résultats révèlent qu'un seul ovaire de l'ensemble de l'échantillon examiné présentait une malformation morphologique. Cependant, l'étude microscopique a révélé que la quasi-totalité des femelles infestées présentaient des anomalies : kyste et atresia accentuée pour 17% et 38% du sous-échantillon examiné, respectivement. L'étude montre clairement que ce sont les gonades des grands spécimens, qui sont d'ailleurs les plus infestées par les nématodes parasites, qui sont touchées par ces anomalies.

Horse mackerel *Trachurus trachurus* (Linnaeus, 1758) is an economically important species of the Mediterranean Sea. In Algeria, it is caught by trawlers at around 280 tons per year (FAO, 2013). In addition, it is of great nutritional value, since it contains high levels of polyunsaturated fatty acids which consumption is supposed to be beneficial for human health (Shahidi and Miraliakbari, 2004, 2005).

Trachurus trachurus is among the fish species that are the most infested by various species of anisakid nematode in Spain (Adroher *et al.*, 1996; Gutiérrez-Galindo *et al.*, 2010), Atlantic waters (MacKenzie *et al.*, 2004), Egypt (Morsy *et al.*, 2012), Morocco (Abattouy *et al.*, 2014) and Algeria (Ichlal *et al.*, 2015, 2017).

The nematodes of the genus *Anisakis* (Nematoda, Ascaridida) are parasites of the digestive tract of cetaceans. They use a great number of fish species as intermediate or

paratenic hosts in their complex life cycle (Smrzlić *et al.*, 2012; Tantanasi *et al.*, 2012). Several studies demonstrated that the host specificity of *Anisakis* spp. is low since it was identified in many different fish families (Skov *et al.*, 2009; Klimpel *et al.*, 2010).

Anisakid parasites have a great negative impact on teleost fish health and stocks. Indeed, these parasites induce severe inflammatory reactions with tissue deformation and haemorrhages in Atlantic cod, Atlantic salmon and sea trout (Beck *et al.*, 2008; Noguera *et al.*, 2009; Levsen and Berland, 2012; Haarder *et al.*, 2013; Buchmann and Mehrdana, 2016). The presence of *Anisakis* larvae in the tissues affects the normal function of these organs and may affect the behaviour, the physiological state, health and survival of the host (Sprengel and Luchtenberg, 1991; Rohlwing *et al.*, 1998). In addition, Clarke *et al.* (2006) reported that nematode para-

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sites can affect the incidence of atresia in fish. Atresia is a common process in the ovaries of fish and other vertebrates (Guraya, 1986; Hirshfield, 1991). This involutive process regulates fish egg production, allowing females to recover part of the energy invested in oocytes (Guraya, 1986). However, high incidence of atresia can prevent proper development of oocytes and probably affects fish fecundity (Clarke *et al.*, 2006). On the other hand, large and persistent atretic follicles can become cysts by an atypical swelling of the follicular envelop (Tomkiewicz *et al.*, 2003; Witthames *et al.*, 2010).

Reports regarding the effect of Anisakid nematodes on *T. trachurus* health are very scarce. Soric *et al.* (2012) reported that *T. trachurus* infested by *Anisakis simplex* (Rudolphi, 1809) larvae show significant differences in body shape between strongly and weakly parasitized fish. However, effects of these nematodes on the horse mackerel gonads are poorly documented. Ichalal *et al.* (2016) reported for the first time that Anisakids could induce macroscopic and microscopic intersex in horse mackerel *T. trachurus*. The present study aims to describe abnormalities in relation with nematode parasite infestation on *T. trachurus* gonads.

MATERIEL AND METHODS

Sample collection and treatment

953 *Trachurus trachurus* were randomly collected from commercial fisheries from the Gulf of Bejaia, in the Eastern coast of Algeria, from February 2013 to March 2014. Total and standard lengths and weights of all specimens were measured to the nearest 0.1 cm and 0.1 g, respectively. Sex was identified according to the external appearance of *T. trachurus* gonads (colour and tissue aspect) (Macer, 1974; Walsh *et al.*, 1990; Costa, 2001; Karlou-Riga, 2003). Total length and weight and age of infested and non infested females were tested statistically by student's t-test using the statistical software MINITAB 13.31 (2000).

Age determination

Otolith extraction was performed through gill opening. It consisted in cutting the gill isthmus and in bending the head back away from the rest of the body; the prootic bulla were

then carefully cracked and otoliths were extracted (Secor *et al.*, 1992). Otolith sagittae were mounted with drop of glue in glass slides, ground along the longitudinal plane using increasing granularity sandpaper (400 and 1200 grain). The exposed surface was then polished and smoothed using successively alumina paste and felt polishing. Finally, the glass slides were observed in binocular microscope for otolith reading (Waldron and Kerstan, 2001).

Parasitological examination

Gills, skin, fins, mouth, liver, intestines and ovaries of fish were examined for any parasitic form, using a stereomicroscope (Morsy *et al.*, 2013). Light and scanning electronic microscopy (SEM) studies were performed on nematode specimens in order to characterize their morphology according to Ichalal *et al.* (2015). Calculated parasitological indexes were: prevalence (P), which is the number of infested fishes divided by the number of examined fishes, expressed as a percentage; mean intensity (mI), representing the total number of parasites of a particular taxon divided by the number of infested fish (Bush *et al.*, 1997).

Histological study

A subsample of 24 *T. trachurus* specimens was analyzed. Individuals were chosen according to their nematode parasite infestation rate. Gonads were fixed in 10% neutralized formalin and divided into equal pieces of transverse 5-mm thickness portions. These portions were then dehydrated through increasing ethanol concentrations (70-95%), cleared in xylene and embedded in paraffin. Histological sections of 3- μ m thickness were then performed using a Leica RM2025 rotary microtome. Sections were mounted on glass microscope slides, stained with Mayer's haemalun-eosin, and mounted with Canada balsam. Samples were then examined by light microscopy and photographed using a digital camera.

RESULTS

Prevalence and morphometry

External examination of fish samples collected indicated absence of any fish body malformations. During internal

Table I. – Mean morphometric values of healthy and infested *Trachurus trachurus*. sd: standard deviation; SL: Standard length; TL: Total length; TW: Total weight.

Parameters	Healthy (n = 832)			Infested (n = 121)		
	Male (n = 88)	Female (n = 108)	Immature (n = 636)	Male (n = 44)	Female (n = 41)	Immature (n = 36)
TL (mean $\pm$ sd) cm	17.95 $\pm$ 4.11	17.01 $\pm$ 4.13	14.78 $\pm$ 1.98	19.67 $\pm$ 4.33	19.62 $\pm$ 4.28	15.62 $\pm$ 4.62
SL (mean $\pm$ sd) cm	14.84 $\pm$ 3.42	14.06 $\pm$ 3.43	11.96 $\pm$ 1.55	16.41 $\pm$ 3.66	16.25 $\pm$ 3.58	12.58 $\pm$ 3.87
TW (mean $\pm$ sd) g	49.60 $\pm$ 25.48	39.84 $\pm$ 25.59	24.64 $\pm$ 10.11	60.92 $\pm$ 28.19	59.55 $\pm$ 26.70	29.99 $\pm$ 28.92
Age (mean $\pm$ sd) years	3 $\pm$ 1.42	2 $\pm$ 1.42	1 $\pm$ 0.93	3 $\pm$ 1.49	3 $\pm$ 1.46	2 $\pm$ 1.55

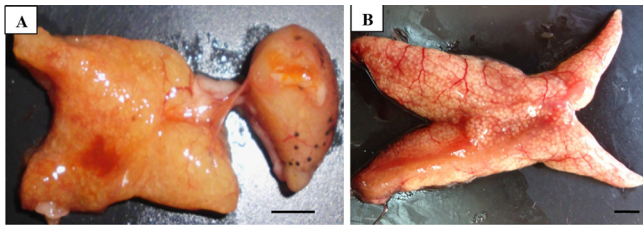


Figure 1. – Morphology of *Trachurus trachurus* gonads. **A**: Compartmented ovary: ovarian strand separated into two lobes; **B**: Normal ovary. Scale bar = 1 cm.

examination, nematode parasites belonging to Anisakidae family were encountered in organs of the abdominal cavity inside the intestine and ovaries.

The total parasitological indexes of nematode infestation among all fish samples collected during the period of study were: prevalence $P = 12.70\%$ and mean intensity $mI = 2.6$ parasites/infested fish. It was noticed that gonads show a higher incidence of infestation (45.19%) than viscera (43.27%) and intestines (11.54%).

Table I summarizes the morphometric data. We noted that infested specimens were larger and older than healthy ones. The numerical results of the statistical t-test were for length,

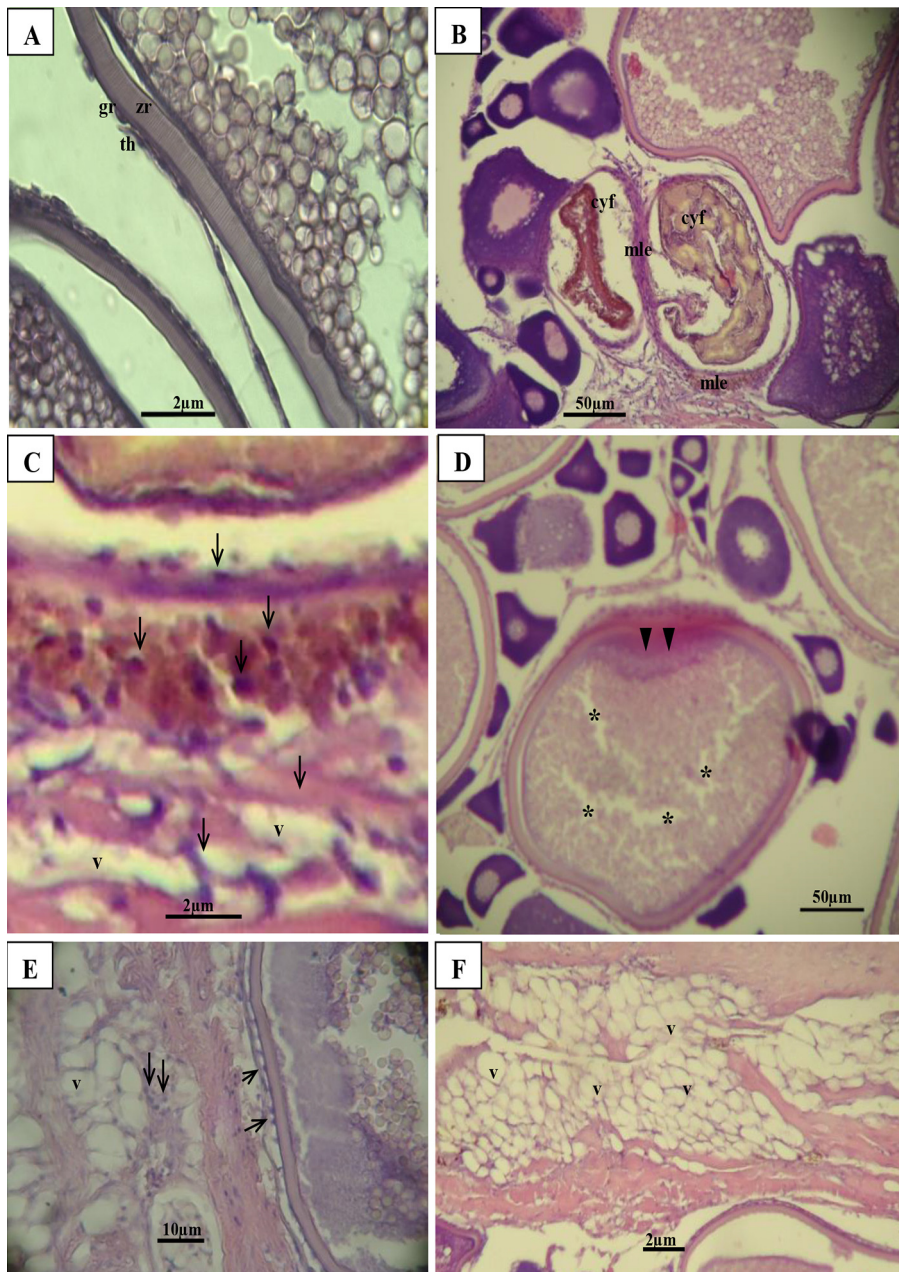


Figure 2. – Microphotographs of cross-sections of horse mackerel ovaries (Mayer's haemalum-eosine staining). **A**: Normal mature follicle; **B**: Cystic follicles with **C**: Proliferation of follicular cell layers (black arrows); **D**: Normal atretic oocyte showing invasion of the oocyte yolk by the granulosa cells (arrowheads) and appearance of several vacuoles (asterisk); **E**: Stratified squamous epithelium structure of a cyst with disorganized cells (black arrows) and **F**: Vacuoles. cyf: cystic follicle; gr: granulosa; mle: multi-layered epithelium; th: theca; v: vacuole; zr: zona radiata.

weight and age: $P = 0.0001$, $P = 0.0001$, $P = 0.005$, respectively. In conclusion, a significant difference was observed between infested and non infested females.

Gonadal abnormalities

Macroscopic features

A macroscopic malformation, which is compartmentation, represented 0.67% of the total examined females ($n = 149$). Compartmentation features were manifested by the division of the ovary into two lobes (Fig. 1A) compared to the normal one (Fig. 1B).

Microscopic features

Among 24 gonads histologically examined, cysts were observed in four infested females measuring between 17.7 and 22.9 cm. Follicular cyst represent 16.66% of the examined subsample.

Cyst structure

In the normal mature follicle, the oocyte is surrounded by three cell layers: the outer theca followed by the granulosa then the zona radiata (Fig. 2A). Cysts are abnormal structures in which follicular cells disorganize by proliferating and forming a multilayered epithelium (Fig. 2B, C). In the normal atretic process, cells from the granulosa invade the cytoplasm of the oocyte. Therefore, the ooplasm is degraded by forming several vacuoles, until complete degeneration of the oocyte (Fig. 2D). However, in cyst structure, an atypical swelling of follicular layers was observed instead of normal atresia leading to cyst formation. Cyst envelop is a stratified squamous epithelium with disorganized cells and several vacuoles (Fig. 2E, F).

Incidence of atresia

T. trachurus is an asynchronous species, ovaries of non infested females showed normal histological structure with oocytes at various maturation stages (Fig. 3A). However, histological analysis revealed that nine infested ovaries of the examined subsample (37.5%) showed a high incidence of atresia, oocyte detachment from its follicular envelope and breaking of the follicular layer (Fig. 3B).

Parasitological analysis and abnormalities

The parasitic infestation rate was calculated for all the examined subsample and results are showed in the table II. According to the table II, all individuals with gonad abnormality showed a high parasitic infestation rate.

DISCUSSION

The present study demonstrated, for the first time, the presence of ovarian abnormalities induced by parasites in

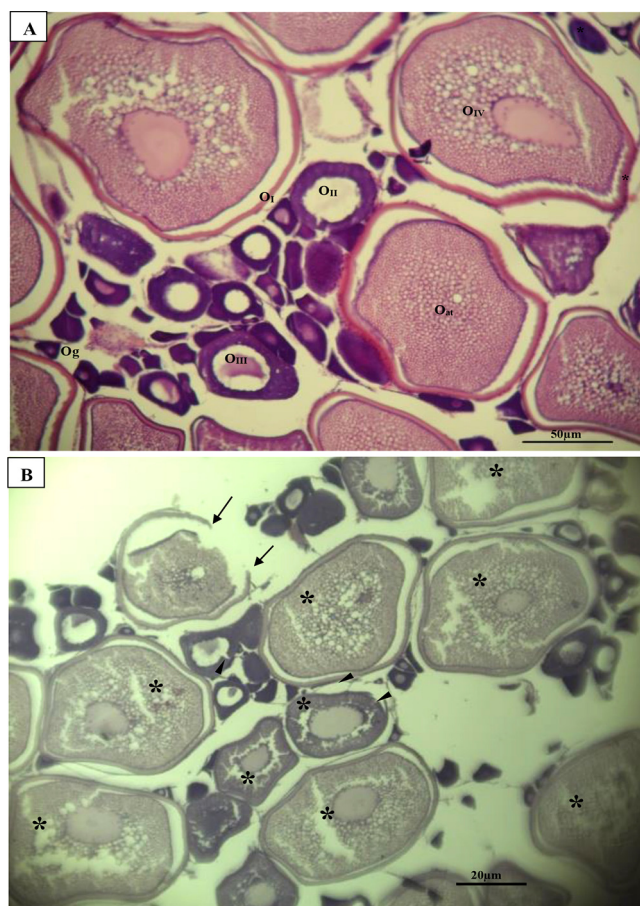


Figure 3. – Microphotographs of cross-section of horse mackerel ovaries (Mayer's haemalum-eosine staining). **A:** Normal histological structure with oocytes at various maturation stages; **B:** High incidence of atresia (asterisk), oocyte detachment from follicular layers (arrowheads) and breaking of the ovarian follicle (arrows). O_I: Oocyte in stage I; O_{II}: Oocyte in stage II; O_{III}: Oocyte in stage III; O_{IV}: Oocyte in stage IV; O_{at}: atretic oocyte; O_g: Oogonia.

horse mackerel *T. trachurus* from the eastern coast of Algeria.

In our previous study, Ichalal *et al.* (2016) reported for the first time macroscopic and microscopic intersex as abnormality in the same species from the same locality. Authors demonstrated that parasites could be the cause of this gonad deformity.

The current results show that parasitism, a stressful factor for wild fish, was associated with a large range of ovarian disorders. Parasites affected fish gonads either at macroscopic or microscopic level. At macroscopic level, parasitism was associated with gonad malformation, which is called compartmentation. Whereas, at microscopic level, parasites induced ovarian cysts and high incidence of atresia. These ovarian abnormalities were already reported in fish by Itoh *et al.* (2004), Clarke *et al.* (2006), Bittner *et al.* (2009), Al-Jahdali and Hassanine, (2010), Parsakhanghah *et al.* (2011) and Sanoun *et al.* (2012).

Table II. – Parasitological indexes of nematodes according to healthy and malformed gonads. mI: mean intensity; n: number of individuals; P: prevalence.

Type of abnormalities	Percentage of abnormalities	Date of capture	Parasitological indexes	
			P (%)	mI
Macroscopic malformation (compartmentation)	0.67% of the total females	06 Jun. 2013	100	7.0
Microscopic malformation (Cyst structure)	16.66 % of the subsample	26 Mar. 2013 (n = 2) 06 Jun. 2013 22 Dec. 2013	100	4.5
Microscopic malformation (incidence of atresia)	37.5% of the subsample	24 Feb. 2013 26 Mar. 2013 (n = 3) 29 Apr. 2013 06 Jun. 2013 29 Oct. 2013 20 Nov. 2013 22 Dec. 2013	100	4.5
Healthy gonads	0%	24 Feb. 2013 26 Mar. 2013 08 Oct. 2013 20 Nov. 2013 19 Jan. 2014 (n = 2)	0	0

Based on macroscopic evaluation, the compartmentation is a morphological abnormality, showing the same atypical characters than described by Bernet *et al.* (2004). These authors reported that the intersex and compartmentation abnormalities in whitefish *Coregonus* spp. (Linnaeus, 1758) were considered like true gonad deformations.

Focusing on microscopic analysis of gonad histological sections, some abnormal follicular and oocyte structures were observed, forming ovarian cysts. These cysts were observed as abnormal structures concerning the oocyte with the different surrounding follicular layers. The structure of the cyst included an abnormally shaped oocyte surrounded by several layers of disrupted follicular cells as well as numerous vacuoles. These criteria were observed by Tomkiewicz *et al.* (2003), Witthames *et al.* (2010) and Domínguez-Petit *et al.* (2011), describing the structure of ovarian cysts of gadoid fish and suggesting that they were sometimes resulting from atresia.

Atresia is a process by which oocytes and follicles undergo resorption, which is identified by histological criteria (Hunter and Macewicz, 1985). This is a normal involutive process common in the ovaries of fish and other vertebrates (Saidapur, 1978; Guraya, 1986; Hirshfield, 1991).

So, due to atresia, fish can regulate their egg production. However, in some cases, oocytes can be encapsulated in cystic structures that might remain in the ovary for months, altering female reproductive potential in future spawning seasons (Domínguez-Petit *et al.*, 2011).

The incidence of atresia is reportedly affected by food availability (Solemdal, 1997; Bromley *et al.*, 2000), parasitic infestations (Clarke *et al.*, 2006), environmental conditions

such as temperature (Linares-Casenave *et al.*, 2002; Privalkhin, 2003), pH or the presence of pollutants (Wootton, 1990; Domínguez-Petit and Saborido-Rey, 2005).

Clarke *et al.* (2006) reported that follicular atresia was induced by parasites, particularly the nematode *Philometra saltatrix* (Ramachandran, 1973), that can prevent the development of the ovaries of bluefish *Pomatomus saltatrix* (Linnaeus, 1766).

In the present report, high incidence of atresia, oocyte detachment from its follicular envelope and breaking of the ovarian follicle, were noted from heavy infested ovaries. These effects of nematode parasites on host ovaries are in accordance with those reported by Clarke *et al.* (2006), Mir *et al.* (2012) and Mohammed *et al.* (2017) in bluefish *P. saltatrix*, freshwater fish *Clarias gariepinus* (Burchell, 1822) and grouper fish *Epinephelus microdon* (Bleeker, 1856) gonads, respectively.

In fish, it is well established that after the spawning season, atresia intensity is higher in species with indeterminate fecundity than in species with determinate fecundity (Murua and Saborido-Rey, 2003). According to these authors, *T. trachurus* is a batch spawner, with indeterminate fecundity. In the present study, results showed high incidence of atresia, probably in relation with parasite infestation, *i.e.* all the highly infested ovaries revealed a high incidence of atresia.

From this, we can suggest that nematode parasites could be the cause of the ovarian abnormalities observed in this study. Furthermore, anisakid parasites induce severe inflammatory reactions with tissue deformation affecting the normal function of organs and may affect behaviour, physiological state, health and survival of Atlantic cod *Gadus morhua*

(Linnaeus, 1758), Atlantic salmon *Salmo salar* (Linnaeus, 1758) and sea trout *Salmo trutta* (Linnaeus, 1758) (Sprengel and Lüchtenberg, 1991; Rohlwing *et al.*, 1998; Beck *et al.*, 2008; Noguera *et al.*, 2009; Levsen and Berland, 2012; Haarder *et al.*, 2013; Buchmann and Mehrdana, 2016). Recently, Ichalal *et al.* (2016) suggested that intersexuality in a gonochoric species, *T. trachurus*, may be related to the nematode infestation rate.

The mechanisms underlying gonad deformity in relation to parasitological status remain less understood. Many authors associated macroscopic and microscopic abnormalities with anthropogenic factors and pollutions (Bittner *et al.*, 2009; Prado *et al.*, 2011; Sanchez *et al.*, 2011; Baynes *et al.*, 2012; Blazer *et al.*, 2012; Kadji *et al.*, 2012).

Nevertheless, reports suggest that parasites could interfere with endocrine system at hormonal level (Beckage, 1993; Jobling and Tyler, 2003). A significant decrease in the gonadotropin secretion in the blood stream was recorded with the presence of nematode parasite inhibiting gonadal development (Mir *et al.*, 2012). So, nematode parasites could induce gonadal malformations by disrupting hormonal secretions. These hormones are involved in the proper development of fish gonads.

This study emphasizes the need for a search of pollution and parasitic nematodes relationships, as well as their negative effects on fish health.

REFERENCES

- ABATTOUY N., VALERO LOPEZ A., LOZANO MALDONADO J., BENAJIBA M.H. & MARTIN-SANCHEZ J., 2014. – Epidemiology and molecular identification of *Anisakis pegreffii* (Nematoda: Anisakidae) in the horse mackerel *Trachurus trachurus* from northern Morocco. *J. Helminthol.*, 88: 257-263.
- ADROHER F.J., VALERO A., RUIZ-VALERO J. & IGLESIAS L., 1996. – Larval anisakids (Nematoda: Ascaridoidea) in horse mackerel (*Trachurus trachurus*) from the fish market in Granada, Spain. *Parasitol. Res.*, 82: 319-322.
- AL-JAHDAL M.O. & HASSANINE R.M. EL-S., 2010. – Ovarian abnormality in a pathological case caused by *Myxidium* sp. (Myxozoa, Myxosporidia) in one spot snapper fish *Lutjanus monostigma* (Teleostei, Lutjanidae) from the Red Sea. *Acta Parasitol.*, 55(1): 1-7.
- BAYNES A., GREEN C., NICOL E., BERESFORD N., KANDA R., HENSHAW A., CHURCHLEY J. & JOBLING S., 2012. – Additional treatment of wastewater reduces endocrine disruption in wild fish – a comparative study of tertiary and advanced treatments. *Environ. Sci. Technol.*, 46: 5565-5573.
- BECK M., EVANS R., FEIST S.W., STEBBING P., LONGSHAW M. & HARRIS E., 2008. – *Anisakis simplex sensu lato* associated with red vent syndrome in wild Atlantic salmon *Salmo salar* in England and Wales. *Dis. Aquat. Org.*, 82: 61-65.
- BECKAGE N.E., 1993. – Endocrine and neuro-endocrine host – parasite relationships. *Receptor*, 3: 233-245.
- BERNET D., WAHLI T., KUENG C. & SEGNER H., 2004. – Frequent and unexplained gonadal abnormalities in whitefish (central alpine *Coregonus* sp.) from an alpine oligotrophic lake in Switzerland. *Dis. Aquat. Org.*, 61: 137-148.
- BITTNER D., BERNET D., WAHLI T., SEGNER H., KUNG C. & LARGIADE C.R., 2009. – How normal is abnormal? Discrimination between deformations and natural variation in gonad morphology of European whitefish *Coregonus lavaretus* J. *Fish. Biol.*, 74: 1-21.
- BLAZER V.S., IWANOWICZ L.R., HENDERSON H., MAZIK P.M., JENKINS J.A., ALVAREZ D.A. & YOUNG J.A., 2012. – Reproductive endocrine disruption in smallmouth bass (*Micropterus dolomieu*) in the Potomac River basin: spatial and temporal comparisons of biological effects. *Environ. Monit. Assess.*, 184: 4309-4334.
- BROMLEY P.J., RAVIER C. & WITTHAMES P.R., 2000. – The influence of feeding regime on sexual maturation, fecundity and atresia in first-time spawning turbot. *J. Fish Biol.*, 56(2): 264-278.
- BUSH A.O., LAFFERTY K.D., LOTZ J.M. & SHOSTAK A.W., 1997. – Parasitology meets ecology on its own terms: Margolis *et al.* revisited. *J. Parasitol.*, 83: 575-583.
- BUCHMANN K. & MEHRDANA F., 2016. – Effects of anisakid nematodes *Anisakis simplex* (s.l.), *Pseudoterranova decipiens* (s.l.) and *Contracaecum osculatatum* (s.l.) on fish and consumer health. *Food Waterborne Parasitol.*, 4: 13-22.
- COSTA A.M., 2001. – Contribuição para o estudo da fecundidade temporal e espacial do carapau (*Trachurus trachurus* L.) na costa portuguesa. Dissertação original apresentada para acesso à Categoria de Investigador Auxiliar, 180 p. Instituto de Investigação das Pescas e do Mar (IPIMAR).
- CLARKE L.M., DOVE A.D.M. & CONOVER D.O., 2006. – Prevalence, intensity, and effect of a nematode (*Philometra saltatrix*) in the ovaries of bluefish (*Pomatomus saltatrix*). *Fish. Bull.*, 104: 118-124.
- DOMÍNGUEZ-PETIT R., & SABORIDO-REY F., 2005. – New atretic structures identified in ovary of European hake (*Merluccius merluccius*, L. 1758) in Galician coast. *ICES Annual Science Conference*, Sep. 20-24, 2005 (Aberdeen, UK). CM 2005/Q: 36.
- DOMÍNGUEZ-PETIT R., ALONSO-FERNÁNDEZ A. & SABORIDO-REY F., 2011. – Incidence and significance of cystic structures in the ovaries of gadoid fish. *Sci. Mar.*, 75(2): 359-368.
- FAO, 2013. – FAOSTAT. Food and Agriculture Organization of the United Nations.
- GURAYA S.S., 1986. – The Cell and Molecular Biology of Fish Oogenesis. Monogr. Dev. Biol., 18: 1-223. Karger Medical and Scientific Publishers.
- GUTIÉRREZ-GALINDO J.F., OSANZ-MUR A.C. & MORAVENTURA M.T., 2010. – Occurrence and infection dynamics of anisakid larvae in *Scomber scombrus*, *Trachurus trachurus*, *Sardina pilchardus* and *Engraulis encrasicolus* from Tarragona (NE Spain). *Food Control*, 21: 1550-1555.
- HAARDER S., KANIA P.W., BAHLOOL Q.M. & BUCHMANN K., 2013. – Expression of immune relevant genes in rainbow trout following exposure to live *Anisakis simplex* larvae. *Exp. Parasitol.*, 135: 564-569.
- HIRSHFIELD A.N., 1991. – Development of follicles in the mammalian ovary. *Int. Rev. Cytol.*, 124: 43-102.
- HUNTER J.R. & MACEWICZ B.J., 1985. – Rates of atresia in the ovary of captive and wild northern anchovy, *Engraulis mordax*. *Fish. Bull.*, 83: 119-136.
- ICHALAL K., RAMDANE Z., IDER D., KACHER M., IGUEROUADA M., TRILLES J.P., COURCOT L. & AMARA R., 2015. – Nematodes parasitizing *Trachurus trachurus* (L.) and *Boops boops* (L.) from Algeria. *Parasitol. Res.*, 114(11): 4059-4068.

- ICHALAL K., RAMDANE Z., IGUER-OUADA M. & KACHER M., 2016. – First observation of intersex in *Trachurus trachurus* (Carangidae) from the Eastern Coast of Algeria: are nematodes the causative factor? *Cybium*, 40(3): 225-233.
- ICHALAL K., CHIKHOUNE A., RAMDANE Z., IGUER-OUADA M. & KACHER M., 2017. – The parasite fauna of *trachurus trachurus* (Linnaeus, 1758) (Teleostei: Carangidae) from the eastern coast of Algeria. *Bull. Soc. Zool. Fr.*, 142(1): 29-45.
- ITO N., KOMIYAMA H., UE KI N. & OGA WA K., 2004. – Early developmental stages of a protozoan parasite, *Marteilioides chungmuensis* (Paramyxea), the causative agent of the ovary enlargement disease in the Pacific oyster *Crassostrea gigas*. *Int. J. Parasitol.*, 34: 1129-1135.
- JOBLING S. & TYLER C.R., 2003. – Endocrine disruption, parasites and pollutants in wild freshwater fish. *Parasitology*, 126: S103-S108.
- KADJI D. H., BENSLIMANE S., CHEVALIER C., KADJI B., EXBRAYAT J.M. & IGUER-OUADA M., 2012. – First observation of intersex in barbel *Barbus callensis* (Valenciennes, 1842) collected in Soummam River (Algeria). *Cybium*, 36(4): 531-538.
- KARLOU-RIGA C., 2003. – Reproduction, atresia and fecundity of horse mackerel (*Trachurus trachurus*) in the Saronikos Gulf (Greece). Report of the Working Group on Mackerel and Horse Mackerel Egg Surveys. ICES Doc. CM 2003/G: 7, Ref. D.
- KLIMPEL S., BUSCH M.W., SUTTON T. & PALM H.W., 2010. – Meso- and bathy-pelagic fish parasites at the Mid-Atlantic Ridge (MAR): low host specificity and restricted parasite diversity. *Deep-Sea Res.*, 57: 596-603.
- LEVSEN A. & BERLAND B., 2012. – Anisakis species. In: Fish Parasites, Pathobiology and Protection, 18 (Woo P.T.K. & Buchmann K., eds), pp. 298-309. CAB International.
- LINARES-CASENAVE J., VAN EENENNAAM J.P. & DOROSHOV S.I., 2002. – Ultrastructural and histological observations on temperature-induced follicular ovarian atresia in the white sturgeon. *J. Appl. Ichthyol.*, 18: 382-390.
- MACER C.T., 1974. – The reproductive biology of the horse mackerel *Trachurus trachurus* (L.) in the North Sea and English Channel. *J. Fish Biol.*, 6: 415-438.
- MACKENZIE K., CAMPBELL N., MATTIUCCI S., RAMOS P., PEREIRA A. & ABAUNZA P., 2004. – A checklist of the protozoan and metazoan parasites reported from the Atlantic horse mackerel, *Trachurus trachurus* (L.). *Bull. Eur. Ass. Fish Pathol.*, 24 (4), 180.
- MIR T.A., KAUR P. & MANOHAR. S., 2012. – Pathogenic effects of nematode parasite *Eustrongylides* sp. larvae on serum LH level and histology of gonads of freshwater fish, *Clarias gariepinus*. *Recent Res. Sci. Technol.*, 4(2): 24-26.
- MOHAMMED S.Y., ABDELRHMAN N.M., MASRI M.A. & IBRAHIM M.Y., 2017. –Histopathological changes in the intestines and gonad of grouper fish *Epinephelus microdon* infected with nematode parasites, Red Sea Coast, Sudan. *Red Sea Univ. J. Basic Appl. Sci.*, 2(spec. issue 2): 350-360.
- MORSY K., BASHTAR A.R., ABDEL-GHAFFAR F., MEHLHORN H., AL QURAIISHY S., EL-MAHDI M., AL-GHAMDI A., MOSTAFA N., 2012. – First record of anisakid juveniles (Nematoda) in the European sea bass *Dicentrarchus labrax* (family: Moronidae), and their role as bio-indicators of heavy metal pollution. *Parasitol. Res.*, 110(3): 1131-1138.
- MORSY K., BASHTAR A.R., ABDEL-GHAFFAR F., AL QURAIISHY S., AL GHAMDI A. & MOSTAFA N., 2013. – First identification of four trypanorhynchid cestodes: *Calitetrarhynchus speciosus*, *Pseudogrillotia* sp. (Lacistorhynchidae), *Kotorella pronosoma* and *Nybelinia bisulcata* (Tentaculariidae) from Sparidae and Mullidae fish. *Parasitol. Res.*, 112(7): 2523-2532.
- MURUA H. & SABORIDO-REY F., 2003. – Female reproductive strategies of marine fish species of the North Atlantic. *J. Northwest Atl. Fish. Sci.*, 33: 23-31
- NOGUERA P., COLLINS C., BRUNO D., PERT C., TURNBULL A., MCINTOSH A., LESTER K., BRICKNELL I., WALLACE S. & COOK P., 2009. – Red vent syndrome in wild Atlantic salmon *Salmo salar* in Scotland is associated with *Anisakis simplex sensu stricto* (Nematoda: Anisakidae). *Dis. Aquat. Org.*, 87: 199-215.
- PARSAKHANGHAH A., MOJAZIAMIRI B., SHARIFPOUR I., JALALIJAFARI B. & MOTALEBI A.A., 2011. – Gonads tissue changes of *Chalcalburnus mossulensis* (Heckel, 1843) infected by *Ligula intestinalis* (Cestoda). *Iran. J. Fish. Sci.*, 10(1): 85-94.
- PRADO P.S., SOUZA C.C., BAZZOLI N. & RIZZO E., 2011. – Reproductive disruption in lambari *Astyanax fasciatus* from a Southeastern Brazilian reservoir. *Ecotoxicol. Environ. Saf.*, 74: 1879-1887.
- PRIVALIKHIN A.M., 2003. – Resorption of developing oocytes as a regulatory mechanism of formation of individual and population fecundity in Walleye Pollock *Theragra chalcogramma* (Gadidae). *J. Ichthyol.*, 43(6): 454-463.
- RAMACHANDRAN P., 1973. – *Philometra saltatrix* sp. n., infecting the gonads of the common bluefish *Pomatomus saltatrix* (L.) of the New England coast of the United States. *Zool. Anz.*, 191: 325-328.
- ROHLWING T.M., PALM H.W. & ROSENTHAL H., 1998. – Parasitisation with *Pseudoterranova decipiens* (Nematoda) influences the survival rate of the European smelt *Osmerus eperlanus* retained by a screen wall of a nuclear power plant. *Dis. Aquat. Org.*, 32: 233-236.
- SAIDAPUR S.K., 1978. – Follicular atresia in the ovary of non-mammalian vertebrates. *Int. Rev. Cytol.*, 54: 225-244.
- SANCHEZ W., SREMSKI W., PICCINI B. et al. [12 authors], 2011. – Adverse effects in wild fish living downstream from pharmaceutical manufacture discharges. *Environ. Int.*, 37: 1342-1348.
- SANOUN G.H., ABDESLEM A., SITHAN L.A. & SOVAN L., 2012. – Impact of *Ligula intestinalis* (L., 1758) (Cestode), on the growth of *Barbus setivimensis* (Cyprinidae) in a lake system in Algeria. *C. R. Biol.*, 335: 300-309.
- SECOR D.H., DEAN J.M. & LABAN E.H., 1992. – Otolith removal and preparation for micro structural examination. In: Otolith Microstructure Examination and Analysis (Stevenson D.K. & Campana S.E., eds). *Can. Spec. Publ. Fish. Aquat. Sci.*, 117: 19-57.
- SHAHIDI F. & MIRALIAKKBARI H., 2004. – Omega-3 (n-3) fatty acids in health and disease: Part 1 – Cardiovascular disease and cancer. *J. Med. Food*, 7: 387-401.
- SHAHIDI F. & MIRALIAKKBARI H., 2005. – Omega-3 (n-3) fatty acids in health and disease: Part 2 – Health effects of omega-3 fatty acids in autoimmune diseases, mental health, and gene expression. *J. Med. Food*, 8: 133-148.
- SKOV J., KANIA P.W. & OLSEN M.M., 2009. – Nematode infections of maricultured and wild fishes in Danish waters: A comparative study. *Aquaculture*, 298: 24-28.
- SMRZLIĆ V.I., VALIĆ D., KAPETANOVIĆ D., KURTOVIĆ B. & TESKEREDŽIĆ E., 2012. – Molecular characterisation of Anisakidae larvae from fish in Adriatic Sea. *Parasitol. Res.*, 111: 2385-2391.
- SOLEMDAL P., 1997. – Maternal effects: a link between the past and the future. *J. Sea Res.*, 37: 213-227.

- SORIC R.E., SEQUEIROS L. C.M., MIRON L. & SOLER A.P., 2012. – Morphometrics for Anisakiasis diagnosis in the North Atlantic horse mackerel (*Trachurus trachurus*). *Sci. Parasitol.*, 13(2): 77-81.
- SPRENGEL G. & LÜCHTENBERG H., 1991. – Infection by endoparasites reduces swimming speed of European smelt *Osmerus eperlanus* and European eel *Anguilla anguilla*. *Dis. Aquat. Org.*, 11: 31-35.
- TANTANASI J., DIAKOU A., TAMVAKIS A. & BATJAKAS I.E., 2012. – *Anisakis* spp. burden in *Trachurus trachurus*. *Helminthologia*, 49(1): 16-20.
- TOMKIEWICZ J., TYBJERG L. & JESPERSEN A., 2003. – Micro and macroscopic characteristics to stage gonadal maturation of female Baltic cod. *J. Fish Biol.*, 62: 253-275.
- WALDRON M.E. & KERSTAN M., 2001. – Age validation in horse mackerel (*Trachurus trachurus*) otoliths. *ICES J. Mar. Sci.*, 58: 806-813.
- WALSH M., HOPKINS P., WITTHAME S P., GREE R-WAL KER P. & WATSON N.J., 1990. – Estimation of total potential fecundity and atresia in the western mackerel stock, 1989. ICE S Document CM 1990/H: 31: 7 p.
- WITTHAMES P.R., THORSEN A. & KJESBU O.S., 2010. – The fate of vitellogenic follicles in experimentally monitored Atlantic cod *Gadus morhua* (L.): application to stock assessment. *Fish. Res.*, 104: 27-37.
- WOOTTON R.J., 1990. – Ecology of Teleost Fishes. Fish and Fisheries Series, 1. 404 p. London, New York: Chapman and Hall.